Specification

Title of the Invention

[0001]   Scanning Optical System

Background of the Invention

[0002]   The present invention relates to a scanning
optical system for forming a laser beam scanning on a scan
target surface.

[0003]   In general, a scanning optical system is employed
in, for example, a laser beam printer, a digital copying
machine, a laser fax machine and a laser plotter. In such
an apparatus, the scanning optical system is used to form a
beam spot which is on/off modulated according to image
information and which scans on the scan target surface
(e.g., a photoconductive drum).

[0004]   Hereafter, a direction in which a beam spot is
scanned on the scan target surface is referred to as a main
scanning direction, and a direction perpendicular to the
main scanning direction on the scan target surface is
referred to as an auxiliary scanning direction. In the
following description, the shape of optical elements,
directions of power of the optical elements and the like

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are described with reference to the main and auxiliary scanning directions on the scan target surface. That is, if an optical element is described to have a refractive power in the main scanning direction, the power affects the beam in the main scanning direction on the scan target surface regardless of the orientation of the element.

[0005]   Fig. 8 shows a configuration of the above mentioned conventional scanning optical system 2. The scanning optical system 2 includes a laser source 70, a line-like image forming optical system 71, a polygonal mirror 72, an imaging optical system 73, and a photoconductive drum 74.

[0006]   The laser beam emitted by the laser source 70 is converged in the auxiliary scanning direction by the line-like image forming optical system 71 to form a line-like image extending in the main scanning direction in the vicinity of a reflective surface of the polygonal mirror 72 rotating about its rotational axis at a constant angular speed.

[0007]   The beam emerged from the line-like image forming optical system 71 is dynamically deflected by the polygonal mirror 72 within a predetermined angular range. Then, the imaging optical system 73 converges the deflected laser beam on the scan target surface to form a beam spot scanning in the main scanning direction at a constant speed.

Since an outer surface (i.e., the scan target surface) of

the photoconductive drum 74 is moved in the auxiliary

scanning direction by rotation of the photoconductive drum

74 about its rotational axis, a two dimensional image

consisting of a plurality of dots can be formed on the

outer surface of the photoconductive drum 74.

[0008]   Meanwhile, the polygonal mirror 72 is required to

be configured such that all of the reflective surfaces

thereof are exactly parallel with the rotational axis of

the polygonal mirror 72. However, to make all of the

reflective surfaces of the polygonal mirror exactly

parallel with the rotational axis thereof during

manufacturing process of the polygonal mirror is impossible.

Therefore, in general, the polygonal mirror 72 includes a

so-called facet error in which one or more reflective

surfaces slightly tilt with respect to the rotational axis.

[0009]   The facet error will be explained in detail with

reference to Figs. 9A, 9B and 10. Fig. 9A is a perspective

view of the polygonal mirror 72. Fig. 9B is a side view of

the polygonal mirror 72 viewed along a line perpendicular

to the rotational axis of the polygonal mirror 72. If a

reflective surface is tilted with respect to the rotational

axis of the polygonal mirror 72 as shown by a broken line

in Fig. 9A, a beam reflected by the tilted reflective

surface deviates in the auxiliary scanning direction from

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an ideal optical path as shown by a dashed arrow in Fig. 9B.

Consequently, the beam spot is formed at a position shifted

in the auxiliary scanning direction form an ideal position

on the scan target surface.

[0010]   To avoid ill effects caused by the facet error,

the scanning optical system 2 employs a configuration

explained below. Fig. 10 is an optical block diagram of the

scanning optical system 2 viewed along a line perpendicular

to the auxiliary scanning direction. As shown in Fig. 10, a

position of a reflective surface of the polygonal mirror 72

and a position at which the line-like image is formed by

the line-like image forming optical system 71 are set

substantially consistent with each other. Further, the

position of the line-like image and the outer surface of

the photoconductive drum 74 (i.e., the scan target surface)

are set optically conjugate with each other in the

auxiliary scanning direction with respect to the imaging

optical system 73.

[0011]   In Fig. 10, the reflective surface indicated by a

solid line 72c shows a situation in which the facet error

is not caused, and the reflective surface indicated by a

broken line 72d shows a situation in which the facet error

is caused. Since the position of the line-like image and

the outer surface of the photoconductive drum 74 are set

optically conjugate with each other, even if the lin -like

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image is reflected by a tilted reflective surface (72d) of the polygonal mirror 72, an image point of the beam reflected by the tilted reflective surface 72d coincides with an image point of the beam reflected by a normal reflective surface (72c). In Fig. 10, a beam Ld indicated by broken lines is the beam reflected by the tilted reflective surface 72d, and a beam Lc indicated by solid lines is the beam reflected by the normal reflective surface 72c.

[0012]   By employing the configuration shown in Fig. 10 to avoid the ill effects of the facet error, the polygonal mirror 72 is not required to be configured such that each reflective surface is exactly parallel with the rotational axis of the polygonal mirror. Accordingly, the manufacturing cost of the scanning optical system 2 can be reduced.

[0013]   A point at which the beam proceeding toward the polygonal mirror 72 is reflected by a reflective surface of the polygonal mirror 72 is referred to as a "deflection point". Fig. 11 illustrates a change of the deflection point caused in connection with rotation of the polygonal mirror 72. As shown in Fig. 11, when the polygonal mirror 72 is positioned at a rotational position A_0, the beam proceeding toward the polygonal mirror 72 is reflected at a point P_0 on the reflective surface 72c. Meanwhile, when the

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polygonal mirror 72 is positioned at a rotational position
A_1, the beam proceeding toward the polygonal mirror 72 is
reflected at a point P_1 on the reflective surface 72c. As a
result, the deflection point shifts by a distance d_0 along
an optical path of the beam proceeding toward the polygonal
mirror 72 from the point P_0 to the point P_1.

[0014]   Since a deflection angle which is an angle formed
between a central axis of the beam proceeding toward the
polygonal mirror 72 and a reflective surface of the
polygonal mirror changes between the rotational position A_0
and the rotational position A_1, the change of the
deflection point is also considered as a phenomenon caused
in connection with a change of the deflection angle.

[0015]   Such a change of the deflection point inevitably
occurs because a distance from a center C of the polygonal
mirror 72 to the reflective surface 72c varies depending on
positions on the reflective surface 72.

[0016]   In a case where the position at which the line-
like imaged is formed coincides with the point P_0, if the
polygonal mirror 72 is positioned at the rotational
position A1, the position at which the line-like image is
formed shifts by the distance d_0 with respect to the
current deflection point P_1. As a result, the conjugate
relationship between the position of the line-like image
and the outer surface of the photoconductive drum 74 is

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lost. That is, in actuality, the conjugate relationship

holds only at a certain deflection angle.

[0017]   Fig. 12 is a side view of the scanning optical

system 2 illustrating the above mentioned phenomenon of the

change of the deflection point. In Fig. 12, a numerical

reference 72a indicates a position of the reflective

surface of the polygonal mirror when the conjugate relation

ship stands (i.e., when the deflection point is positioned

at the point P_0 in Fig. 11). A numerical reference 72b

indicates a position of the reflective surface in a

situation where the deflection point is shifted from a

proper position 72a.

[0018]   A broken line 72e shown at the position 72b

indicates a reflective surface of the polygonal mirror 72

tilted due to the facet error. As described above, the

conjugate relationship is lost when the deflection point

shifts form the proper position 72a. Therefore, when the

beam is reflected by the tilted reflective surface 72e at

the shifted deflection position 72b, a beam spot of a beam

Le reflected by the tilted reflective surface 72e is formed

at a position shifted in the auxiliary scanning direction

on the scan target surface from an ideal position.

[0019]   That is, the beam spot of the beam Le shifts from

the beam spot of a beam Lc reflected by the normal

reflective surface (72c) at the proper deflection position

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72a. As a result, a scan line which is a locus of the beam spot on the scan target surface shifts in the auxiliary scanning direction from an ideal position.

[0020]   Hereafter, such a phenomenon in which the scan line shifts on the scan target surface in the auxiliary scanning direction is referred to as "jitter in the auxiliary scanning direction". Further, the amount of the jitter in the auxiliary scanning direction is referred to as "jitter amount".

[0021]   The jitter amount changes depending on: a lateral magnification of the imaging optical system 73 in the auxiliary scanning direction (m); a tilt angle of a reflective surface of the polygonal mirror with respect to the rotational axis of the polygonal mirror (φ); and a shift amount of the deflection point from the position at which the line-like image is formed (d_0). The jitter amount increases as at least one of m, φ and d_0 increases.

[0022]   Foe example, the jitter amount y' may be defined as:

$$y' = |2md_1\varphi|$$

where d_1 represents the maximum shift amount of the deflection point from the position at which the line-like image is formed.

[0023]   Meanwhile, a polygonal mirror has a plurality of reflective surfaces. Therefore, in many cases, tilt angles

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φ vary among the plurality of reflective surfaces. If the tilt angles φ vary among the plurality of reflective surfaces, the jitter amounts also vary among the plurality of reflective surfaces of the polygonal mirror. In Fig. 13, normal scan lines 89 having no jitter amounts are indicated on the left side, and scan lines 90 having jitter amounts JI which vary among the plurality of reflective surfaces are indicated on the right side.

[0024]　　When such variations of the jitter amounts occur, a jitter pattern PA repeats with rotations of the polygonal mirror. The variations of the jitter amount deteriorate imaging quality. In particular, when a back focus (i.e., a distance between the imaging optical system and the photoconductive drum) is lengthened to downsize a size of an apparatus (for example, a printer) accommodating the scanning optical system and to improve flexibility of mechanical design of the apparatus, the jitter amount increases and thereby the degree of reduction in imaging quality exceeds a permissible amount.

[0025]　　Preferably, the jitter amount is less than or equal to 5.0 μm when the resolution is 600 dpi (dots per inch), although the permissible jitter amount varies depending on resolution dpi. However, there is a case where the jitter amount of the conventional scanning optical system exceeds the permissible jitter amount of 5.0 μm. For

example, the jitter amount of a scanning optical system

shown in a practical example 4 of Japanese Provisional

Publication NO. HEI7-113950 takes a value of 7.0 μm.

[0026]   Since, in general, if the number of reflection

surfaces is less than or equal to 6 and if the lateral

magnification in the auxiliary scanning direction $|m| >$

1.85, the jitter amount produced by a conventional design

technique of the scanning optical system exceeds 5.0 μm,

which deteriorates the imaging quality considerably.

[0027]   In Japanese Provisional Publication NO. HEI 5-

142495, a configuration of a scanning optical system to

avoid an ill effect of an error in which a distance between

a rotational axis of a polygonal mirror and each reflective

surface of the polygonal mirror varies from one reflective

surface to another reflective surface is disclosed. However,

the error of the polygonal mirror discussed in this

publication is a manufacturing error of the polygonal

mirror with regard to the distance between the rotational

axis and each reflective surface. Therefore, the error

discussed in the publication HEI 5-142459 is different from

the above mentioned phenomenon of the change of the

deflection point which occurs inevitably.

[0028]   As described above, a problem caused by the

phenomenon of the change of the deflection point (i.e., the

variations of the jitter amounts) has not been resolved.

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One of fundamental solutions to this problem is to reduce
the jitter amount by employing a polygonal mirror
manufactured with extremely high accuracy.

[0029]   However, a polygonal mirror manufactured using a
typical manufacturing process usually has the facet error
of about 180" (=0.00087 rad). To manufacture a polygonal
mirror having precision higher than that of the polygonal
mirror manufactured using the typical manufacturing process
(i.e., to manufacture a polygonal mirror having the facet
error less than 180") considerably increases the
manufacturing cost of the polygonal mirror.

Summary of the Invention

[0030]   The present invention is advantageous in that it
provides a scanning optical system which is capable of
reducing the jitter amount in the auxiliary scanning
direction caused in connection with the change of the
deflection point and the facet error.

[0031]   According to an aspect the invention, there is
provided a scanning optical system for emitting a beam
scanning in a main scanning direction. The scanning optical
system is provided with a light source that emits the beam,
a line-like image forming optical system that converges the
beam emitted by the light source in an auxiliary scanning

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direction which is perpendicular to the main scanning direction, a polygonal mirror that rotates about its rotational axis to deflect the beam emerged from the line-like image forming optical system in the main scanning direction, and an imaging optical system that converges the beam deflected by the polygonal mirror to form a beam spot scanning on a scan target surface in the main scanning direction.

[0032]   In this structure, the line-like image forming optical system forms a line-like image extending in the main scanning direction in the vicinity of a reflective surface of the polygonal mirror, and if the number of reflective surfaces of the polygonal mirror is less than or equal to six and if $|m| > 1.85$, the following condition (1) is satisfied:

$$r < 5\cos(w/2f)/[2|m|\{1-\cos(w/2f)\}] \quad \cdots \ (1)$$

where r represents a radius of an inscribed circle of the polygonal mirror, m represents a lateral magnification of the imaging optical system in the auxiliary scanning direction, f represents a focal length of the imaging optical system in the main scanning direction, and w represents half of a scanning width.

[0033]   With this configuration, the jitter amount can be reduced less than or equal to the permissible amount of 5.0 μm even if the polygonal mirror includes the facet error of

about 180".

[0034]　　Optionally, the scanning optical system may satisfy the following condition (2):

$$w/f > 0.70 \qquad \qquad \cdots (2).$$

With this configuration, even if the scanning optical system has relatively wide field angle w/f larger than 0.7 (w/f > 0.7), the jitter amount can be reduced less than or equal to the permissible amount of 5.0 because the scanning optical system satisfies the condition (1).

[0035]　　Still optionally, if N > 4, the following condition (3) may be satisfied:

$$wN/2\pi f > 0.55 \qquad \qquad \cdots (3)$$

where N represents the number of the reflective surfaces of the polygonal mirror.

[0036]　　In a particular case, the imaging optical system may have two lenses. With this structure, the lateral magnification of the imaging optical system in the auxiliary scanning direction can be reduced, and therefore the jitter amount can be effectively reduced.

[0037]　　In a particular case, refractive power in an auxiliary scanning plane of a lens surface of the imaging optical system located nearest to the scan target surface may be the largest of all lens surfaces of the imaging optical system. The auxiliary scanning plane is a plane which includes an optical axis of the imaging optical

system and which is perpendicular to the main scanning

direction. With this structure, the lateral magnification

of the imaging optical system in the auxiliary scanning

direction can be reduced, and therefore the jitter amount

can be effectively reduced.

[0038]   Optionally, a jitter amount may be less than or

equal to 5.0 μm, the jitter amount being defined as a

distance between a position of a scan line and an ideal

position of the scan line in the auxiliary scanning

direction on the scan target surface.

[0039]   Still optionally, when the polygonal mirror is

situated such that a position at which the line-like image

is formed lies on a reflective surface of the polygonal

mirror, the beam reflected from the polygonal mirror may

proceed along an optical axis of the imaging optical system.

Brief Description of the Accompanying Drawings

[0040]   Fig. 1 shows an optical block diagram of a

scanning optical system according to an embodiment of the

present invention;

[0041]   Fig. 2 illustrates scanning operation in which a

beam is dynamically deflected by a rotating polygonal

mirror of the scanning optical system;

[0042]   Fig. 3 is a side view of the scanning optical

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system viewed along a line perpendicular to an auxiliary
scanning direction;

[0043]   Fig. 4 is a graph illustrating a jitter amount of
a comparative example;

[0044]   Fig. 5 is a graph illustrating the jitter amount
of a first example;

[0045]   Fig. 6 is a graph illustrating the jitter amount
of a second example;

[0046]   Fig. 7 is a graph illustrating the jitter amount
of a third example;

[0047]   Fig. 8 shows a configuration of a conventional
scanning optical system;

[0048]   Fig. 9A is a perspective view of a polygonal
mirror of the scanning optical system shown in Fig. 8;

[0049]   Fig. 9B is a side view of the polygonal mirror
shown in Fig. 9A;

[0050]   Fig. 10 is an optical block diagram of the
conventional scanning optical system viewed along a line
perpendicular to the auxiliary scanning direction
illustrating a optical path when a facet error occurs;

[0051]   Fig. 11 illustrates a change of a deflection
point caused in connection with rotation of the polygonal
mirror;

[0052]   Fig. 12 is a side view of the scanning optical
system shown in Fig. 10 illustrating an optical path when

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the facet error and a change of the deflection point occur;
and

[0053]   Fig. 13 illustrates normal scan lines having no
jitter amounts and scan lines having jitter amounts which
vary among a plurality of reflective surfaces of the
polygonal mirror.

Detailed Description of the Embodiments

[0054]   Hereinafter, an embodiment according to the
invention is described with reference to the accompanying
drawings.

[0055]   Each of Figs. 1 and 2 shows an optical block
diagram of a scanning optical system 1 according to an
embodiment of the present invention. The optical block
diagram shown in each of Figs. 1 and 2 is viewed along line
parallel with a rotational axis 15a of a polygonal mirror
15.

[0056]   As shown in Figs. 1 and 2, the scanning optical
system 1 includes a laser source 10 which emits a laser
beam, a line-like image forming optical system 13 having a
collimator lens 11 and a cylindrical lens 12, the polygonal
mirror 15 which has a form of a hexagonal prism and which
rotates about its rotational axis 15a, and an imaging
optical system 18 having a first lens 16 and a second lens

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17. A scan target S corresponds to, for example, an outer surface of a photoconductive drum. In Fig. 2, a scanning operation in which a beam is dynamically deflected by the rotating polygonal mirror 15 is illustrated.

[0057]   In this embodiment, a direction perpendicular to both of the rotational axis 15a of the polygonal mirror 15 and an optical axis of the imaging optical system 18 corresponds to a main scanning system, and a direction parallel with the rotational axis 15a of the polygonal mirror 15 corresponds to an auxiliary scanning direction. An arrow shown in Fig. 1 indicates the main scanning direction. A plane which includes the optical axis of the imaging optical system 18 and which is perpendicular the rotational axis 15a of the polygonal mirror 15 is referred to as a main scanning plane. Further, a plane which includes the optical axis of the imaging lens system 18 and which is perpendicular to the main scanning plane is referred to as an auxiliary scanning plane.

[0058]   The beam emitted by the laser source 10 as a divergent beam is collimated by the collimator lens 11 to form a collimated beam having an elliptical cross section. The beam emerged from the collimator lens 11 is converged by the cylindrical lens 12 in the auxiliary scanning direction to form a line-like image extending in the main scanning direction in the vicinity of a reflective surface

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of the polygonal mirror 15.

[0059]   The polygonal mirror 15 rotating about the
rotational axis 15a at a constant angular speed dynamically
deflects the beam incident thereon. The imaging optical
system 18 converges the beam deflected by the polygonal
mirror 15 onto the scan target surface S to form a beam
spot scanning in the main scanning direction at constant
speed.

[0060]   Since the scan target surface S is moved in the
auxiliary scanning direction, a plurality of scan lines
having constant intervals are formed on the scan target
surface. By on/off modulating the beam using, for example,
the laser source or a modulator (not shown) according to
image information, a two dimensional image having a
plurality of dots is formed on the scan target surface S.

[0061]   As described above, with regard to the main
scanning direction, the beam emitted by the laser source 10
is not converged when the beam is incident on the polygonal
mirror 15. Then, the beam deflected by the polygonal mirror
15 is converged by the imaging optical system 18 in the
main scanning direction onto the scan target surface.

[0062]   With regard to the auxiliary scanning direction,
the beam emitted by the laser source 10 is converged by the
cylindrical lens 12 in the vicinity of the reflective
surface of the polygonal mirror 15. Then, the beam

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deflected by the polygonal mirror 15 proceeds toward the imaging optical system 18 as a divergent beam and converged by the imaging optical system 18 onto the scan target surface S.

[0063]   More specifically, the polygonal mirror 15 is positioned so that when a position at which the line-like imaged is formed exactly coincides with a deflection point on a reflective surface of the polygonal mirror 15, a chief ray of the beam reflected at the deflection point proceeds along the optical axis of the imaging optical system 18. In this situation (i.e., when the position of the line-like image coincides with the deflection point on the reflective surface of the polygonal mirror 15), the position of the line-like image and the scan target surface S become optically conjugate with each other in regard to the auxiliary scanning direction. Therefore, in this situation, deviation of a scanning position on the scan target surface S in the auxiliary scanning direction caused by the facet error is corrected and eliminated.

[0064]   However, as described above, such a conjugate relationship between the position of the line-like image and the scan target surface does not always hold because the above mentioned "change of the deflection point" is caused in connection with rotations of the polygonal mirror 15. To reduce the "jitter amount" caused by the facet error

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and the loss of the conjugate relationship, the scanning optical system 1 employs the following configuration.

[0065]   That is, if $|m| > 1.85$, the scanning optical system 1 satisfies a condition:

$$r < 5\cos(w/2f)/[2|m|\{1-\cos(w/2f)\}] \qquad \cdots (1)$$

where r represents a radius of an inscribed circle of the polygonal mirror 15, m represents a lateral magnification of the imaging optical system 18 in the auxiliary scanning direction, f represents a focal length of the imaging optical system 18 in the main scanning plane, and w represents half of a scanning width. The scanning width is defined as a length by which the beam spot is scanned on the scan target surface in the main scanning direction.

[0066]   When the condition (1) is satisfied, even if an absolute value of the lateral magnification is larger than 1.85 ($|m|>1.85$), the jitter amount can be suppressed lower than or equal to 5.0 μm.

[0067]   Fig. 3 is a side view of the scanning optical system 1 viewed along a line perpendicular to the auxiliary scanning direction. In Fig. 3, the amount of the change of the deflection point "d_0" is also indicated (see Fig. 11).

[0068]   The scanning optical system 1 further satisfies the following conditions:

$$w/f > 0.70 \qquad\qquad \cdots (2)$$

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$$wN/2\pi f > 0.55 \qquad \cdots (3)$$

where f represents the focal length of the imaging

optical system 18 in the main scanning plane, w represents

half of the scanning width, and N represents the number of

reflective surfaces of the polygonal mirror 15.

[0069]   When the condition (2) is satisfied, even if a

field angle of the scanning optical system is large, the

jitter amount can be sufficiently reduced. The condition

(3) is satisfied when N is larger than 4 (N > 4). If the

number of the reflective surfaces of the polygonal mirror

15 is less than or equal to 4 (N ≤ 4), the amount of the

change of the deflection point "d_0" becomes too big, and

the jitter amount can not be reduced sufficiently.

[0070]   Hereafter, a comparative example which does not

satisfy the condition (1) and three concrete examples

according to the embodiment of the present invention will

be described.

[0071]   In the following examples, there is a case in

which the imaging optical system 18 has a rotationally

asymmetrical optical surface, and such a rotationally

asymmetrical optical surface does not have an axis like a

symmetry axis of a rotationally symmetrical optical surface.

Therefore, a term an optical surface reference axis is

defined as an axis passing through an origin that is set

when the shap of the rotationally asymmetrical optical

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surface is described in a mathematical expression, and the optical surface reference axis will hereafter be regarded as one that corresponds to the symmetry axis of a rotationally symmetrical optical surface (i.e. the optical axis).

[0072]   COMPARATIVE EXAMPLE

[0073]   A scanning optical system of a comparative example has a configuration similar to the scanning optical system 1 according to the embodiment of the present invention. Therefore, the comparative example is explained below using the configuration shown in Figs. 1-3.

[0074]   In the comparative example, a total focal length of the imaging optical system 18 is 140 mm. The imaging optical system 18 has the lateral magnification of -2.15 in the auxiliary scanning direction and has the half scanning width of 108 mm. The polygonal mirror 15 has the radius of the inscribed circle of 20.00 mm and has six reflective surfaces. An angle θ (see Fig. 1) formed between the beam proceeding toward the polygonal mirror 15 and the optical axis of the imaging optical system 18 in the main scanning direction is -80.0°. The angle θ is negative when the beam proceeding toward the polygonal mirror 15 is inclined clockwise with respect to the optical axis of the imaging optical system 18 in the main scanning plane on Fig. 1. The

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angle θ is positive when the beam proceeding toward the polygonal mirror 15 is inclined counterclockwise with respect to the optical axis of the imaging optical system 18 in the main scanning plane on Fig. 1.

[0075]   When these values (m, w and f) are assigned to the condition (1), the radius of the inscribed circle of the polygonal mirror 15 must take a value less than or equal to 14.7 mm. However, since the radius of the inscribed circle of the comparative example is 20.00 mm, the comparative example does not satisfy the condition (1).

[0076]   TABLE 1 shows a concrete numerical configuration of the comparative example from the cylindrical lens 12 through the scan target surface S.

[0077]   TABLE 1

No.	Ry	Rz	D	n
#1	∞	33.20	4.00	1.5107
#2	∞		62.36	
#3			28.00	
#4	-220.00	-220.00	10.00	1.5192
#5	-50.93	-50.93	25.00	
#6	-118.99	25.60	5.00	1.4862
#7	-156.70	-156.70	112.00	

[0078]   In TABLE 1, the character "No." indicates surface numbers that are assigned to optical surfaces in the comparative example starting from a front surface (a beam incident surface) of the cylindrical lens 12. The #1 and #2

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denote the front surface and a rear surface (a beam
emerging surface) of the cylindrical lens 12, respectively.
The #3 denotes the reflective surface of the polygonal
mirror 15. The #4 and #5 denote a front surface (a
polygonal mirror side) and a rear surface (a scan target
surface side) of the first lens 16 of the imaging optical
system 18, respectively. The #6 and #7 denote a front
surface and a rear surface of the second lens 17 of the
imaging optical system 18, respectively.

[0079]   The character "Ry" denotes a radius of curvature
[mm] of each optical surface on its optical axis measured
in the main scanning direction, and "Rz" denotes a radius
of curvature [mm] of each optical surface on its optical
axis measured in the auxiliary scanning direction. The
character "D" denotes the distance [mm] between an optical
surface and a next optical surface measured along the
optical axis, and "n" denotes a refractive index of each
lens at a design wavelength 780 nm (refractive indexes for
the air are omitted).

[0080]   As can be seen from TABLE 1, the front surface of
the cylindrical lens 12 is a cylindrical surface (i.e., a
convex surface), and the rear surface of the cylindrical
lens 12 is a flat surface. The front surface #4 of the
first lens 16 and the rear surface #7 of the second lens 17
are spherical surfaces.

[0081]   The rear surface #5 of the first lens 16 is a rotationally symmetrical aspherical surface. The rotationally symmetrical aspherical surface is expressed by a following equation:

$$X(h) = \frac{\left(\frac{1}{Ry}\right)h^2}{1 + \sqrt{1 - (1+\kappa)^2 h^2 \left(\frac{1}{Ry}\right)^2}} + A_4 h^4 + A_6 h^6 + A_8 h^8 + A_{10} h^{10} \cdots \qquad \cdots (4)$$

where $X(h)$ represents a SAG amount which is a distance between a point on the aspherical surface at a height of h from the optical axis and a plane tangential to the aspherical surface at the optical axis. κ represents a conical coefficient, and A_4, A_6 and A_8 are aspherical coefficients of 4th, 6th and 8th orders, respectively. Ry is the radius of curvature of the rotationally symmetrical aspherical surface on the optical axis indicated in TABLE 1.

[0082]   The conical coefficient and aspherical coefficients of the rear surface #5 of the first lens 16 are indicated in TABLE 2.

[0083]   TABLE 2

	#5
κ	0.0
A_4	1.73E-06
A_6	4.44E-10
A_8	-5.90E-13
A_{10}	2.12E-16

[0084]   The front surface #6 of the second lens 17 is an

anamorphic aspherical surface whose cross section in the main scanning direction is defined by a function of a height from the optical axis in the main scanning direction and whose curvature of a cross section in the auxiliary scanning direction is defined by a function of a height from the optical axis in the main scanning direction.

[0085]   The anamorphic aspherical surface is defined by the following equations.

$$X(Y) = \frac{\left(\frac{1}{Ry}\right)Y^2}{1+\sqrt{1-(1+\kappa)^2 Y^2 \left(\frac{1}{Ry}\right)^2}} + AM_1 Y + AM_2 Y^2 + AM_3 Y^3 + \quad \cdots (5)$$

$$AM_4 Y^4 + AM_5 Y^5 + AM_6 Y^6 + AM_7 Y^7 + AM_8 Y^8 \cdots$$

$$\frac{1}{Rz(Y)} = \frac{1}{Rz} + AS_1 Y + AS_2 Y^2 + AS_3 Y^3 + AS_4 Y^4 + AS_5 Y^5 \quad \cdots (6)$$

$$+ AS_6 Y^6 + AS_7 Y^7 + AS_8 Y^8 \cdots$$

where X(Y) is a SAG amount which is obtained as a function of a coordinate Y extending in the main scanning direction. The SAG amount X(Y) represents a distance between a plane tangential to the anamorphic aspherical surface at the optical axis and a point on a curved line extending along the anamorphic aspherical surface in the main scanning direction and passing the optical axis thereof. 1/Ry represents curvature of the anamorphic aspherical surface in the main scanning direction at the optical axis. Further,

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1/Rz(Y) represents curvature of an arc extending in the auxiliary scanning direction, and the arc is intersecting the curved line at the point whose coordinate is Y. κ represents a conical coefficient, and AM_n is an aspherical coefficient of nth order for the main scanning direction. AS_n is an aspherical coefficient of nth order for determining the curvature in the auxiliary scanning direction.

[0086]   Values of the coefficients for the front surface #6 of the second lens 17 are indicated in TABLE 3.

[0087]   TABLE 3

surface #6   (anamorphic aspherical surface)

$\kappa=0.0$		
$AM_1=$	0.00E+00	$AS_1=$ -2.16E-05
$AM_2=$	0.00E+00	$AS_2=$ -1.04E-06
$AM_3=$	0.00E+00	$AS_3=$ 0.00E+00
$AM_4=$	1.21E-06	$AS_4=$ -2.54E-09
$AM_5=$	0.00E+00	$AS_5=$ 0.00E+00
$AM_6=$	-1.26E-10	$AS_6=$ 9.53E-13
$AM_7=$	0.00E+00	$AS_7=$ 0.00E+00
$AM_8=$	-4.61E-14	$AS_8=$ -1.19E-16
$AM_9=$	0.00E+00	$AS_9=$ 0.00E+00
$AM_{10}=$	1.97E-17	$AS_{10}=$ 0.00E+00
$AM_{11}=$	0.00E+00	$AS_{11}=$ 0.00E+00
$AM_{12}=$	-2.49E-21	$AS_{12}=$ 0.00E+00
$AM_{13}=$	0.00E+00	$AS_{13}=$ 0.00E+00
$AM_{14}=$	5.76E-26	$AS_{14}=$ 0.00E+00

[0088]   The scanning optical system of the comparative example having the above mentioned numerical configuration

has the maximum amount of the change of the deflection point of 1.59 mm. When the jitter amount is defined by the above mentioned definition ($y' = |2md_1\varphi|$) and the tilt angle φ takes a typical value of 0.00087 rad, the maximum jitter amount is 5.9 μm which exceeds the permissible jitter amount of 5.0 μm.

[0089] Fig. 4 is a graph illustrating the jitter amount of the comparative example. In Fig. 4 (and in Figs. 5-7, a vertical axis represents a height Y from the optical axis on the scan target surface S, and a horizontal axis represents a shift amount (i.e., the jitter amount) of the beam spot from an ideal position in the auxiliary scanning direction (unit: mm). As can be seen form Fig. 4, the jitter amount of the comparative example exceeds the permissible jitter amount of 5.0 μm.

[0090] FIRST EXAMPLE

[0091] A first example according to the embodiment of the present invention will be described. A scanning optical system of the first example has a configuration similar to the scanning optical system 1 according to the embodiment of the present invention. Therefore, the first example is explained using the configuration shown in Figs. 1-3.

[0092] In the first example, a total focal length of the imaging optical system 18 is 150 mm. The imaging optical

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system 18 has the lateral magnification of -2.22 in the
auxiliary scanning direction and has the half scanning
width of 108 mm. The polygonal mirror 15 has the radius of
the inscribed circle of 12.1 mm and has six reflective
surfaces. The angle θ (see Fig. 1) formed between the beam
proceeding toward the polygonal mirror 15 and the optical
axis of the imaging optical system 18 in the main scanning
direction is -80.0°.

[0093]　　When these values (m, w and f) are assigned to
the condition (1), the radius of the inscribed circle of
the polygonal mirror 15 must take a value less than or
equal to 16.4 mm. As described above, the first example has
the radius of the inscribed circle of 12.1 mm, and
therefore the first example satisfies the condition (1).

[0094]　　TABLE 4 shows a concrete numerical configuration
of the first example from the cylindrical lens 12 through
the scan target surface S. Symbols and fields of TBALE 4
have the same meanings as those of TABLE 1.

[0095]　　TABLE 4

No.	Ry	Rz	D	n
#1	∞	33.20	4.00	1.5107
#2	∞		62.36	
#3			28.00	
#4	-220.00	-220.00	10.00	1.5192
#5	-53.70	-53.70	27.00	
#6	-121.40	26.46	5.00	1.4862
#7	-157.60	-157.60	120.00	

[0096]   As can be seen from TABLE 4, the front surface of the cylindrical lens 12 is a cylindrical surface (i.e., a convex surface), and the rear surface of the cylindrical lens 12 is a flat surface. The front surface #4 of the first lens 16 and the rear surface #7 of the second lens 17 are spherical surfaces.

[0097]   The rear surface #5 of the first lens 16 is a rotationally symmetrical aspherical surface expressed by the above mentioned equation (4). The conical coefficient and aspherical coefficients of the rear surface #5 of the first lens 16 are indicated in TABLE 5.

[0098]   TABLE 5

	#5
κ	0.0
A_4	1.77E-06
A_6	9.58E-11
A_8	-1.93E-13

[0099]   The front surface #6 of the second lens 17 is an anamorphic aspherical surface expressed by the above mentioned equations (5) and (6). Values of the coefficients for the front surface #6 of the second lens 17 are indicated in TABLE 6.

[0100]   TABLE 6

surface #6   (anamorphic aspherical surface)

$\kappa=0.0$			
$AM_1=$	0.00E+00	$AS_1=$	-1.24E-05
$AM_2=$	0.00E+00	$AS_2=$	-1.51E-06
$AM_3=$	0.00E+00	$AS_3=$	0.00E+00

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$AM_4=$ 1.13E-06

$AM_5=$ 0.00E+00

$AM_6=$ -1.39E-10

$AM_7=$ 0.00E+00

$AM_8=$ -2.26E-14

$AM_9=$ 0.00E+00

$AM_{10}=$ 1.54E-17

$AM_{11}=$ 0.00E+00

$AM_{12}=$ -3.73E-21

$AM_{13}=$ 0.00E+00

$AM_{14}=$ 3.66E-25

$AS_4=$ -2.08E-09

$AS_5=$ 0.00E+00

$AS_6=$ 7.77E-13

$AS_7=$ 0.00E+00

$AS_8=$ -9.95E-17

$AS_9=$ 0.00E+00

$AS_{10}=$ 0.00E+00

$AS_{11}=$ 0.00E+00

$AS_{12}=$ 0.00E+00

$AS_{13}=$ 0.00E+00

$AS_{14}=$ 0.00E+00

[0101]   The scanning optical system of the first example having the above mentioned numerical configuration has the maximum amount of the change of the deflection point of 0.83 mm.   When the jitter amount is defined by the above mentioned definition ($y' = |2md_1\varphi|$) and the tilt angle φ takes a typical value of 0.00087 rad, the jitter amount is 3.2 μm. Therefore, the first example has the sufficiently reduced maximum jitter amount of 3.2 μm.

[0102]   Fig. 5 is a graph illustrating the jitter amount of the first example. As can be seen form Fig. 5, the jitter amount of the first example is sufficiently reduced in comparison with the jitter amount of the comparative example shown in Fig. 4.

[0103]   The first example has w/f of 0.72 and wN/2πf of 0.69. Therefore the first example satisfies the conditions (2) and (3).

[0104]　　SECOND EXAMPLE

[_105]　　A second example according to the embodiment of the present invention will be described. A scanning optical system of the second example has a configuration similar to the scanning optical system 1 according to the embodiment of the present invention. Therefore, the second example is explained using the configuration shown in Figs. 1-3.

[0106]　　In the second example, a total focal length of the imaging optical system 18 is 150 mm. The imaging optical system 18 has the lateral magnification of -2.07 in the auxiliary scanning direction and has the half scanning width of 108 mm. The polygonal mirror 15 has the radius of the inscribed circle of 12.1 mm and has six reflective surfaces. The angle θ (see Fig. 1) formed between the beam proceeding toward the polygonal mirror 15 and the optical axis of the imaging optical system 18 in the main scanning direction is -80.0°.

[0107]　　When these values (m, w and f) are assigned to the condition (1), the radius of the inscribed circle of the polygonal mirror 15 must take a value less than or equal to 17.6 mm. As described above, the second example has the radius of the inscribed circle of 12.1 mm, and therefore the second example satisfies the condition (1).

[0108]　　TABLE 7 shows a concrete numerical configuration of the second example from the cylindrical lens 12 through

the scan target surface S. Symbols and fields of TBALE 7

have the same meanings as those of TABLE 1.

[0109]   TABLE 7

No.	Ry	Rz	D	n
#1	∞	33.20	4.00	1.5107
#2	∞		62.36	
#3			28.00	
#4	-220.00	-220.00	10.00	1.5192
#5	-54.71	-54.71	27.00	
#6	-243.72	-243.72	5.00	1.4862
#7	-380.58	-21.26	120.00	

[0110]   As can be seen from TABLE 7, the front surface of

the cylindrical lens 12 is a cylindrical surface (i.e., a

convex surface), and the rear surface of the cylindrical

lens 12 is a flat surface. The front surface #4 of the

first lens 16 and the front surface #6 of the second lens

17 are spherical surfaces.

[0111]   The rear surface #5 of the first lens 16 is a

rotationally symmetrical aspherical surface expressed by

the above mentioned equation (4). The conical coefficient

and aspherical coefficients of the rear surface #5 of the

first lens 16 are indicated in TABLE 8.

[0112]   TABLE 8

	#5
κ	0.0
A_4	1.55E-06
A_6	-2.38E-11
A_8	-8.65E-14

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[0113]   The rear surface #7 of the second lens 17 is an anamorphic aspherical surface expressed by the above mentioned equations (5) and (6). Values of the coefficients for the rear surface #7 of the second lens 17 are indicated in TABLE 9.

[0114]   TABLE 9

surface #7   (anamorphic aspherical surface)

$\kappa=0.0$

$AM_1=$ 0.00E+00	$AS_1=$ 1.06E-05
$AM_2=$ 0.00E+00	$AS_2=$ 4.32E-06
$AM_3=$ 0.00E+00	$AS_3=$ 0.00E+00
$AM_4=$ -9.06E-07	$AS_4=$ -2.63E-09
$AM_5=$ 0.00E+00	$AS_5=$ 0.00E+00
$AM_6=$ 2.05E-10	$AS_6=$ 7.44E-13
$AM_7=$ 0.00E+00	$AS_7=$ 0.00E+00
$AM_8=$ -6.62E-14	$AS_8=$ -9.40E-17
$AM_9=$ 0.00E+00	$AS_9=$ 0.00E+00
$AM_{10}=$ 1.82E-17	$AS_{10}=$ 0.00E+00
$AM_{11}=$ 0.00E+00	$AS_{11}=$ 0.00E+00
$AM_{12}=$ -3.05E-21	$AS_{12}=$ 0.00E+00
$AM_{13}=$ 0.00E+00	$AS_{13}=$ 0.00E+00
$AM_{14}=$ 2.48E-25	$AS_{14}=$ 0.00E+00

[0115]   The scanning optical system of the second example having the above mentioned numerical configuration has the maximum amount of the change of the deflection point of 0.83 mm. When the jitter amount is defined by the above mentioned definition ($y' = |2md_1\varphi|$) and the tilt angle φ takes a typical value of 0.00087 rad, the jitter amount is 3.0 μm. Therefore, the second example has the sufficiently

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reduced maximum jitter amount of 3.0 μm.

[0116]   Fig. 6 is a graph illustrating the jitter amount of the second example. As can be seen form Fig. 6, the jitter amount of the second example is sufficiently reduced in comparison with the jitter amount of the comparative example shown in Fig. 4.

[0117]   The second example has w/f of 0.72 and wN/2πf of 0.69, and therefore the second example satisfies the conditions (2) and (3).

[0118]   THIRD EXAMPLE

[0119]   A third example according to the embodiment of the present invention will be described. A scanning optical system of the third example has a configuration similar to the scanning optical system 1 according to the embodiment of the present invention. Therefore, the third example is explained using the configuration shown in Figs. 1-3.

[0120]   In the third example, a total focal length of the imaging optical system 18 is 140 mm. The imaging optical system 18 has the lateral magnification of -1.92 in the auxiliary scanning direction and has the half scanning width of 108 mm. The polygonal mirror 15 has the radius of the inscribed circle of 13.9 mm and has six reflective surfaces. The angle θ (see Fig. 1) formed between the beam proceeding toward the polygonal mirror 15 and the optical

axis of the imaging optical system 18 in the main scanning

direction is -80.0°.

[0121]   When these values (m, w and f) are assigned to

the condition (1), the radius of the inscribed circle of

the polygonal mirror 15 must take a value less than or

equal to 17.0 mm. As described above, the third example has

the radius of the inscribed circle of 13.9 mm, and

therefore the third example satisfies the condition (1).

[0122]   TABLE 10 shows a concrete numerical configuration

of the third example from the cylindrical lens 12 through

the scan target surface S. Symbols and fields of TBALE 10

have the same meanings as those of TABLE 1.

[0123]   TABLE 10

No.	Ry	Rz	D	n
#1	∞	33.20	4.00	1.5107
#2	∞		62.36	
#3			28.00	
#4	-220.00	-220.00	10.00	1.5192
#5	-52.20	-52.20	27.00	
#6	-250.85	-250.85	5.00	1.4862
#7	-395.94	-20.78	110.00	

[0124]   As can be seen from TABLE 10, the front surface

of the cylindrical lens 12 is a cylindrical surface (i.e.,

a convex surface), and the rear surface of the cylindrical

lens 12 is a flat surface. The front surface #4 of the

first lens 16 and the front surface #6 of the second lens

17 are spherical surfaces.

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[0125]   The rear surface #5 of the first lens 16 is a rotationally symmetrical aspherical surface expressed by the above mentioned equation (4). The conical coefficient and aspherical coefficients of the rear surface #5 of the first lens 16 are indicated in TABLE 11.

[0126]   TABLE 11

	#5
κ	0.0
A_4	1.51E-06
A_6	-1.12E-10
A_8	3.64E-14

[0127]   The rear surface #7 of the second lens 17 is an anamorphic aspherical surface expressed by the above mentioned equations (5) and (6). Values of the coefficients for the rear surface #7 of the second lens 17 are indicated in TABLE 12.

[0128]   TABLE 12

surface #7   (anamorphic aspherical surface)

$\kappa = 0.0$

$AM_1 =$ 0.00E+00	$AS_1 =$ 1.13E-05
$AM_2 =$ 0.00E+00	$AS_2 =$ 4.30E-06
$AM_3 =$ 0.00E+00	$AS_3 =$ 0.00E+00
$AM_4 =$ -9.16E-07	$AS_4 =$ -2.47E-09
$AM_5 =$ 0.00E+00	$AS_5 =$ 0.00E+00
$AM_6 =$ 2.25E-10	$AS_6 =$ 6.65E-13
$AM_7 =$ 0.00E+00	$AS_7 =$ 0.00E+00
$AM_8 =$ -6.97E-14	$AS_8 =$ -8.21E-17
$AM_9 =$ 0.00E+00	$AS_9 =$ 0.00E+00
$AM_{10} =$ 1.62E-17	$AS_{10} =$ 0.00E+00
$AM_{11} =$ 0.00E+00	$AS_{11} =$ 0.00E+00

$$AM_{12}= -2.27E-21 \qquad AS_{12}= 0.00E+00$$
$$AM_{13}= 0.00E+00 \qquad AS_{13}= 0.00E+00$$
$$AM_{14}= 1.47E-25 \qquad AS_{14}= 0.00E+00$$

[0129]   The scanning optical system of the third example having the above mentioned numerical configuration has the maximum amount of the change of the deflection point of 1.10 mm. When the jitter amount is defined by the above mentioned definition ($y' = |2md_1\varphi|$) and the tilt angle φ takes a typical value of 0.00087 rad, the jitter amount is 3.5 μm. Therefore, the third example has the sufficiently reduced maximum jitter amount of 3.5 μm.

[0130]   Fig. 7 is a graph illustrating the jitter amount of the third example. As can be seen form Fig. 7, the jitter amount of the third example is sufficiently reduced in comparison with the jitter amount of the comparative example shown in Fig. 4.

[0131]   The third example has w/f of 0.77 and wN/2πf of 0.74, and therefore the second example satisfies the conditions (2) and (3).

[0132]   As described above, by satisfying the condition (1), the jitter amount of the scanning optical system can be reduced less than or equal to the permissible jitter amount of 5.0 μm. Even if the total length of the scanning optical system is relatively sort and the back focus of the scanning optical system is relatively long, the jitter

amount can be reduced sufficiently.

[0133]　　Although the present invention has been described in considerable detail with reference to certain preferred embodiments thereof, other embodiments are possible.

[0134]　　The present disclosure relates to the subject matter contained in Japanese Patent Application No. P2002-346973, filed on November 29, 2002, which is expressly incorporated herein by reference in its entirety.